N83 24887

POLARIZER MECHANISM FOR THE SPACE TELESCOPE FAINT OBJECT SPECTROGRAPH

Mark D. Thulson*

ABSTRACT

This paper describes the polarizer mechanism for the Space Telescope Faint Object Spectrograph. This device will allow spectropolarimetric measurements of faint astronomical objects. The mechanism employs a unique arrangement to meet functional requirements in a compact package and with only one actuator. Detailed tolerance analysis and a variety of tests indicate that the polarizer is capable of accurate and reliable performance.

INTRODUCTION

The polarizer mechanism for the Faint Object Spectrograph (FOS) will allow the Space Telescope to obtain spectropolarimetric data on faint astronomical objects. Measurements made using this device will be quite useful to astronomers studying a wide variety of phenomena, especially with the extension into the far ultraviolet made possible by the Space Telescope.

The FOS, shown in Figure 1, has two distinct light paths and digicon photon counting detectors. One detector is red sensitive (1800-8000 Å) and the other is blue sensitive (1150-5000 Å).

Spectropolarimetric data is obtained by introducing a Wollaston prism and waveplate into either of the light paths. The Wollaston prism forms two dispersed images in opposite senses of polarization at the detector. The waveplate is rotated with respect to the stationary prism to analyze for linear and circular polarization. For better coverage of the spectrum, two waveplates with different retardations are used, each with its own Wollaston prism.

MECHANISM DESCRIPTION

The polarizer mechanism must be able to do the following:

- place either of the Wollaston/waveplate pairs in either of the light paths;
- rotate each waveplate with respect to its Wollaston prism; and
- leave both light paths simultaneously clear when the polarizer is not in use.

The mechanism uses an arrangement which accomplishes these requirements with a single actuator and in a compact package. The two Wollaston prisms are fixed to a drum which also contains two holes to

* Martin Marietta Denver Aerospace, Denver, Colorado

clear the optical paths (see Figure 2). The waveplates are mounted in rotating cylinders inside the drum and ahead of the prisms. Each of these cylinders has a 16 tooth gear cut into its outside diameter. Both of these gears mesh with a stationary 17 tooth gear located on the drum's axis of rotation.

Rotating the drum about its centerline allows either Wollaston/ waveplate pair to be inserted into either optical path, or both paths to be cleared simultaneously. Turning the drum 360° rotates the Wollaston prism 360°, and the waveplate 17/16 times as much, or 382.5°. The net effect of one rotation of the drum, then, is to rotate the waveplate 22.5°. Sixteen revolutions of the drum returns the optical elements to their original positions.

The drum is driven through a two stage, 105:1 gear train by a 90° permanent magnet stepper motor as shown in Figure 3. The motor is driven at 50 pulses per second (750 RPM). This means that one 22.5° increment of the waveplate takes 8.4 seconds.

Two eight-bit pin contact encoders provide position feedback. The encoders are geared in such a way (see Figure 4) that a motor step advances encoder A 3.05 counts and encoder B 3.09 counts. In 16 revolutions of the drum, encoder A rotates 80 times and encoder B 81 times, bringing both back to their starting point. As a result, each of the 6,720 steps of the motor required to complete 16 revolutions of the drum is associated with a unique combination of bits from the encoders. The fact that motor steps are separated by slightly more than three counts guarantees that the outputs are unambiguous.

Positional accuracy of the optical elements is determined by the accuracy of the motor's position plus any error in the gear train. The design includes several features to minimize this error. First, spring loaded antibacklash gears are used wherever possible. The 210 tooth gear is a conventional antibacklash gear with two extension springs. The 18 tooth pinion in the second stage is a special antibacklash gear which is preloaded by a small torsion spring mounted inside the gear.

Space does not permit the 16 tooth waveplate gears to be antibacklash. The fixed 17 tooth gear cannot be, because it is engaged by both waveplate gears. The angular position of the waveplate, however, is not as critical as that of the Wollaston prism. Control of center distance and runout to minimize backlash limits this error to an acceptable range.

Second, all gear ratios are integral. As a result, when the mechanism returns to a previous position, all the same gear teeth are in contact and any errors resulting from gear tolerances, bearing runout, and so on are repeatable. This also means that extremely high precision gears are not required - AGMA Q10 gears are sufficiently accurate.

Third, ABEC 7P bearings are used throughout and comparable tolerances are maintained on all housings and shafts. This minimizes

clearances between bearings and housings or shafts and the resulting angular errors.

Finally, the bearings are preloaded axially to eliminate clearance within the bearings themselves. This is done with belleville washers for the rotating drum bearings, a wave spring washer for the intermediate shaft, and compression springs for the waveplate bearings. The use of springs accomodates thermal changes without large changes in preload.

In the event of a failure, activation of a hot wire pinpuller allows two torsion springs to rotate the mechanism completely out of the optical paths to the position shown in Figure 5, allowing continued use of the remainder of the FOS. The holes engaged by the pin are match drilled at assembly to guarantee proper alignment. As a further precaution against binding of the pin, the bolts which attach the pinpuller to the mechanism are left .025 to .076 mm (.001 to .003 inch) loose to allow the pin to freely align itself with the hole.

The entire assembly is attached by six #6-32 screws to a fitting which is, in turn, bonded to two graphite epoxy tubes that are part of the FOS optical bench. Laminated shims at these six points allow any adjustment required for initial alignment. Figure 6 shows the polarizer after installation into the FOS.

MATERIALS AND LUBRICATION

All gears are 416 stainless steel, heat treated to a hardness of Rockwell C32. After final machining, the gears are case hardened to a depth of 5 to 10 μm (.0002 to .0004 inch) by a nitriding process, resulting in a surface hardness of Rockwell RC 60 to 70. The hardened surface will minimize gear wear during the life of the mechanism. Any wear would result in positional errors as well as the generation of particle contamination.

By using the nitriding process, the gears can be cut, then hardened, thus eliminating the need for final grinding of the teeth. Dimensional changes are well within the tolerances for AGMA Q10 gears. The fact that the hardened case is so shallow allows the gears to be drilled and reamed where required for pinning at assembly.

The bearings are 440C stainless steel. All other major parts are aluminum to save weight. All non-functional surfaces are coated with flat black polyurethane paint to mimize optical reflection.

The bearings and gears are lubricated with Braycote 3L-38RP grease. The shaft about which the mechanism rotates when the pinpuller is activated is lubricated by MoS_2 with an impinged binder.

REPEATABILITY ANALYSIS

Some of the more critical requirements for the polarizer have to do with the repeatability of the angular position of the optical elements.

Two kinds of angular error are possible - 1) rotation about the optical axis, or θz; and 2) rotation about an axis perpendicular to the optical axis, or θx and θy (tilt). Either of these can result in both motion of the image at the detector and errors in polarization measurements.

To insure that these requirements would be met, a detailed tolerance analysis was performed prior to fabrication of the mechanism. For a particular requirement, all of the potential error sources were identified and their effect on angular position calculated. Root sum square addition of these contributors resulted in a predicted maximum error.

The largest single source of error in θz for either the Wollaston prisms or waveplates is the stepper motor. Its actual position is specified to be within $\pm 5\%$ of a step, or $\pm 4.5^{o}$, of its nominal position. The resulting error in θz for the Wollaston prisms, then, is $\pm 4.5^{o}/105 = \pm 2.57$ arc min.

Most of the remainder of the error in θz arises from bearing to housing and bearing to shaft clearance. This clearance can induce error in two ways. First, motion of a gear along a line passing through the centers of the mating gears changes the center distance. This results in rotation of the gear which is related to the pressure angle. Motion in a direction perpendicular to a line through the centers also results in rotation of the gear. The resultant of these two components cannot exceed an amount determined by the maximum total clearance in the supporting bearings.

The analysis divides the total possible motion of each gear between these two components in such a way as to maximize the rotational error in question. Bearing runout is also included in the same way to account for the possibility that the outer race rotates with respect to the housing or the inner race with respect to the shaft.

The error in θz for the waveplates is somewhat larger than that for the Wollaston prisms. This is because of the extra pair of bearings involved and the backlash in the waveplate gear meshes.

Repeatability error for θx and θy (tilt) of the Wollaston prisms are calculated from the clearances and runout of the bearings which support the rotating drum. Tilt of the waveplates also includes the effect of the waveplate bearings and manufacturing tolerances for perpendicularity between the waveplate mounting shoulder and bearing lands.

Table 1 summarizes the required, predicted, and measured values for θx, θy and θz for the Wollaston prisms and waveplates. Predicted and measured values compare favorably, and both are well within the requirements.

PROBLEMS AND SOLUTIONS

Minimal problems were encountered during assembly, but one became obvious. Interference between two of the motor mounting screws and the mounting bracket prevented full rotation of the mechanism when the pinpuller was operated (see Figure 4). Two small modifications solved this problem. First, stress analysis showed that three screws were more than adequate to mount the motor, so one was removed. Second, a small area was machined from the mounting bracket to clear the other interfering screws.

TESTING

Functional tests were performed to verify that the polarizer performed as expected. These tests included repeatedly operating the motor a specified number of steps, then reading the two encoders. The encoders consistently produced reliable and repeatable data.

Further testing verified that the polarizer could be operated closed loop, as it will be in the FOS. Here the mechanism is commanded to a position and the encoders are read to determine when it has arrived. This also worked reliably.

Optical tests were performed to measure image motion and polarization measurement errors. These tests indicate that errors are well within required values and that the polarizer is capable of excellent performance.[1]

The mechanism was also tested under random vibration with no problems.

CONCLUSION

At this writing (December 1982) the polarizer has been installed (along with the other mechanisms, optics, and detectors) into the FOS. The entire FOS is presently undergoing thermal vacuum testing.

ACKNOWLEDGEMENT

This work was performed under NASA Goddard contract NAS5-24463 and purchase contract E07121-3143 from the Regents of the University of California (Faint Object Spectrograph for the Space Telescope).

---

1 Allen, R.G., and Angel, J.R.P., "Performance of the Spectropolarimeter for the Space Telescope Faint Object Spectrograph", Proceedings of the S.P.I.E., Instrumentation and Astronomy IV, 1982.

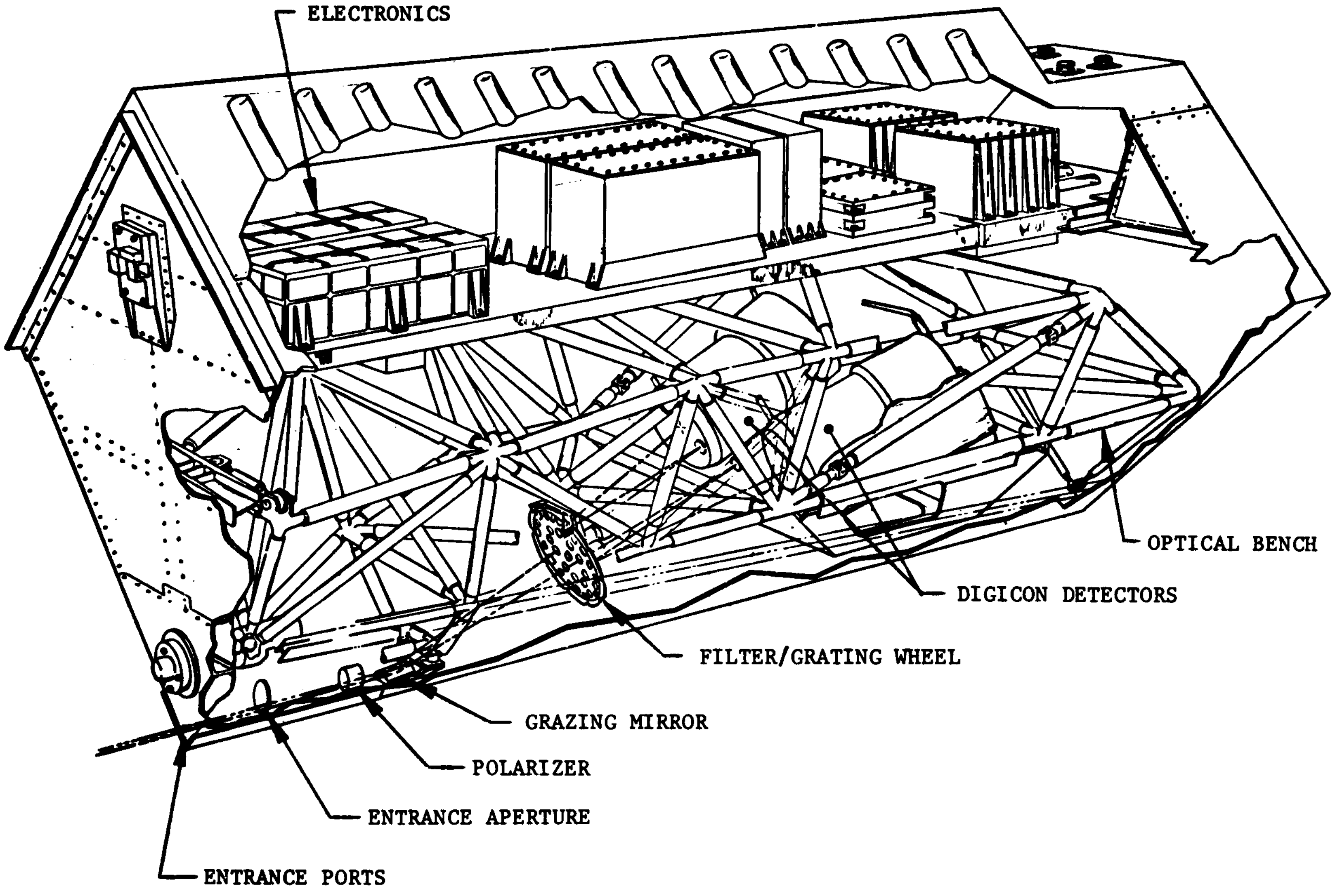

Figure 1. - Faint Object Spectrograph

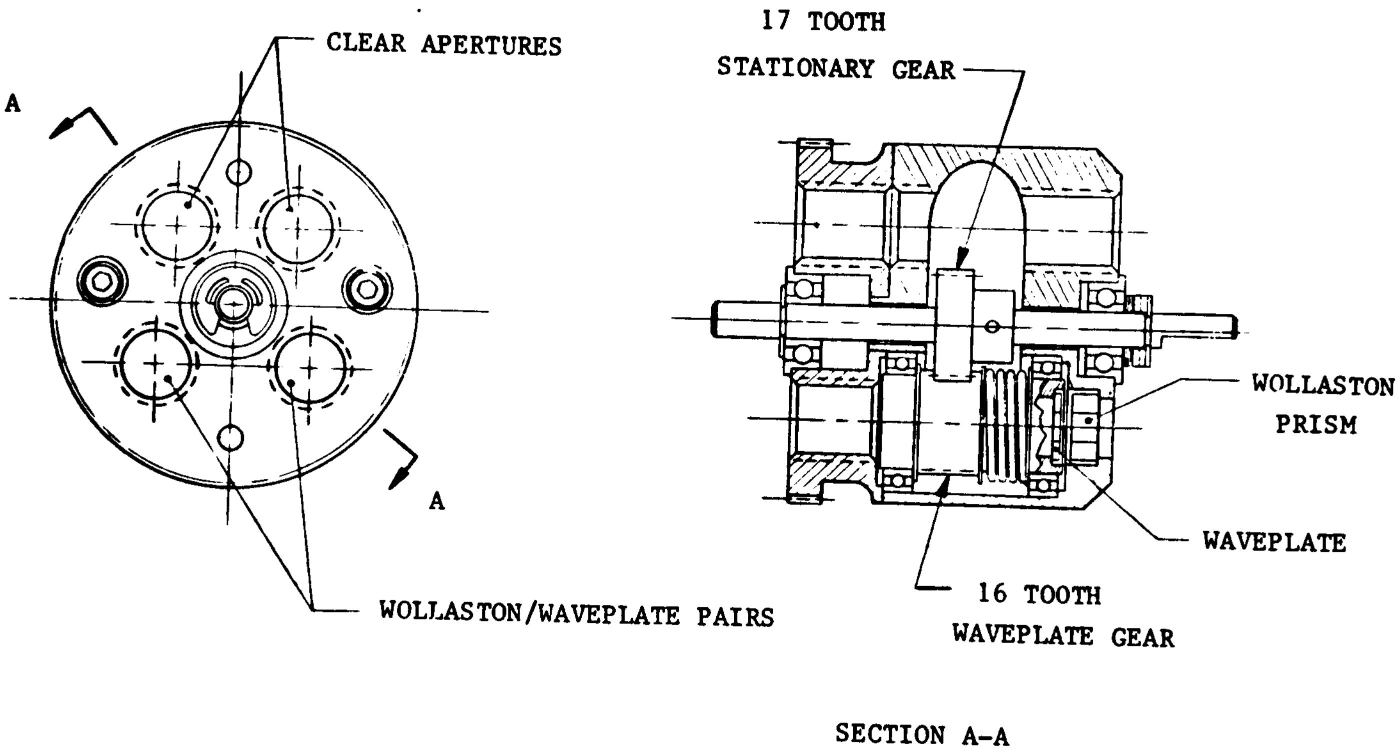

Figure 2. - Rotating Drum

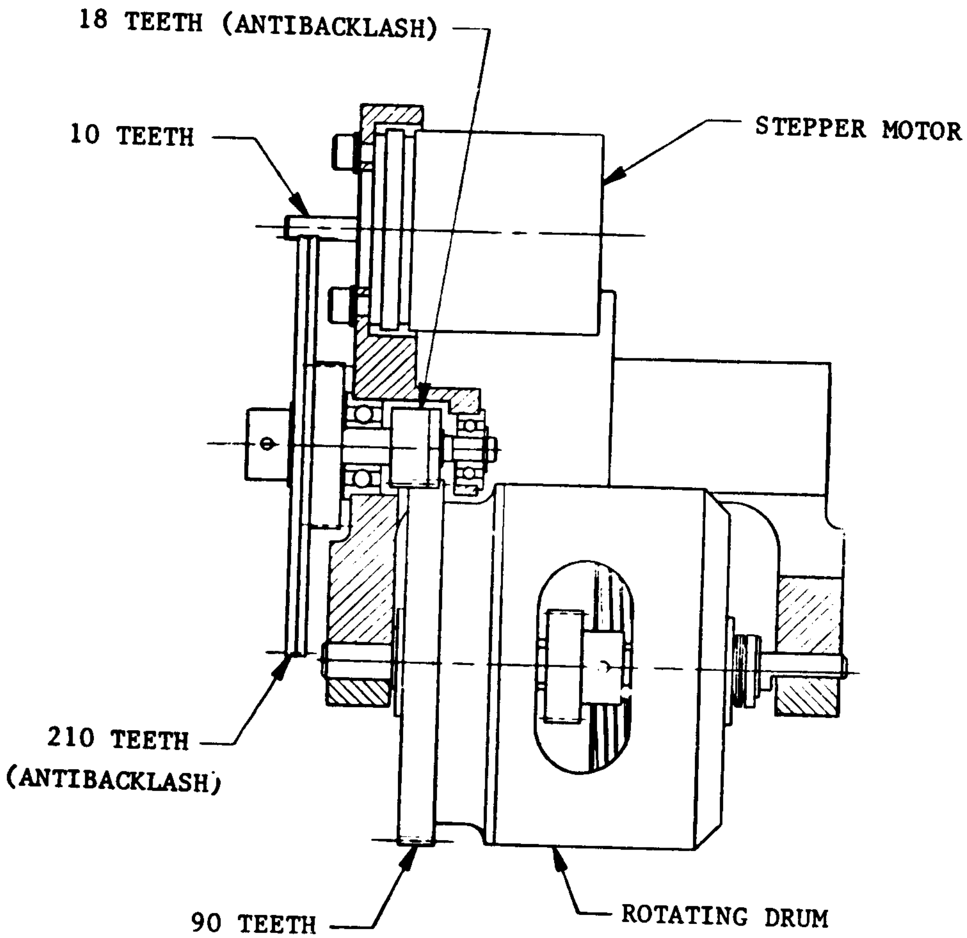

Figure 3. - Gear Train

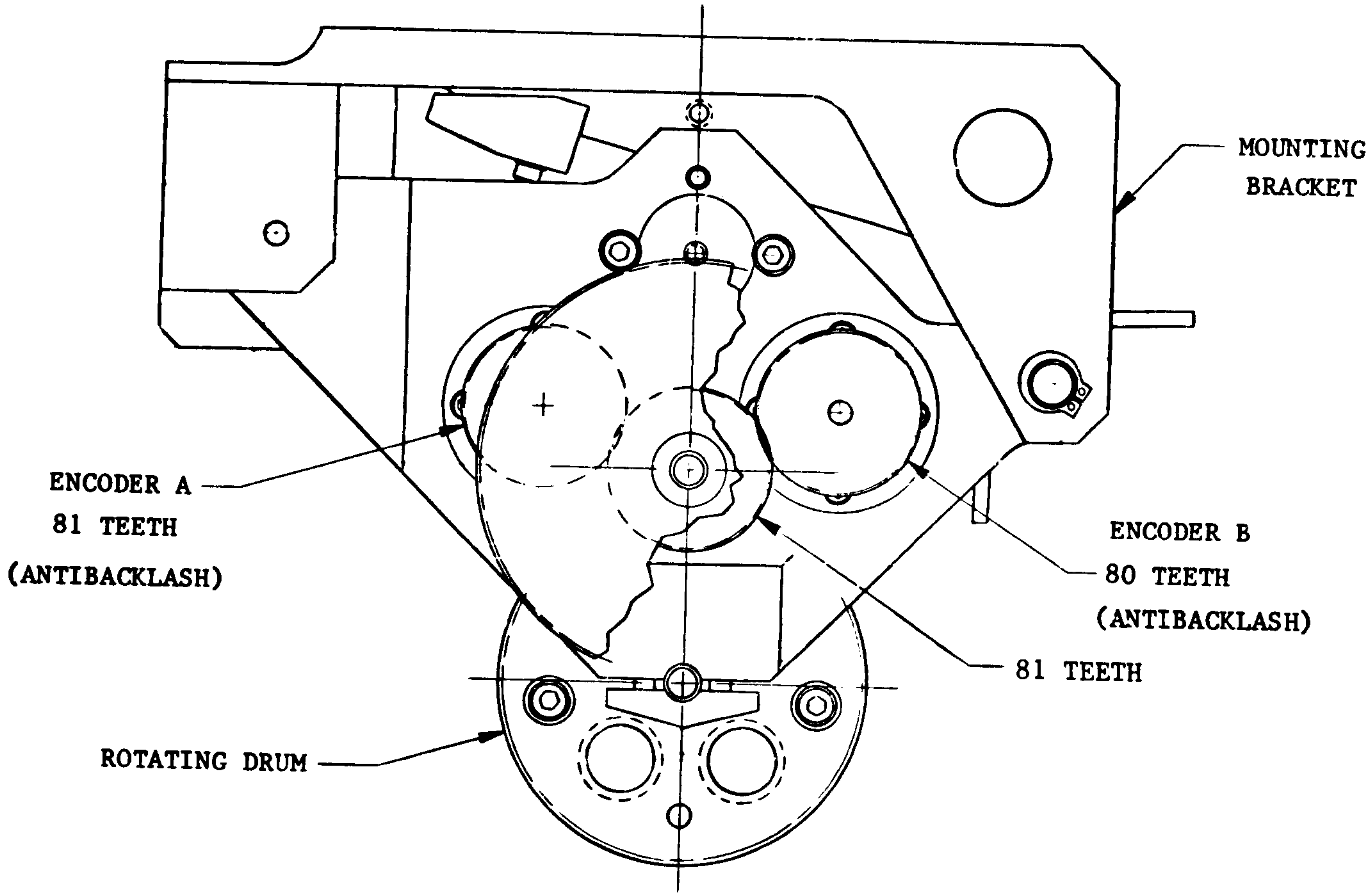

Figure 4. - Encoder Gears

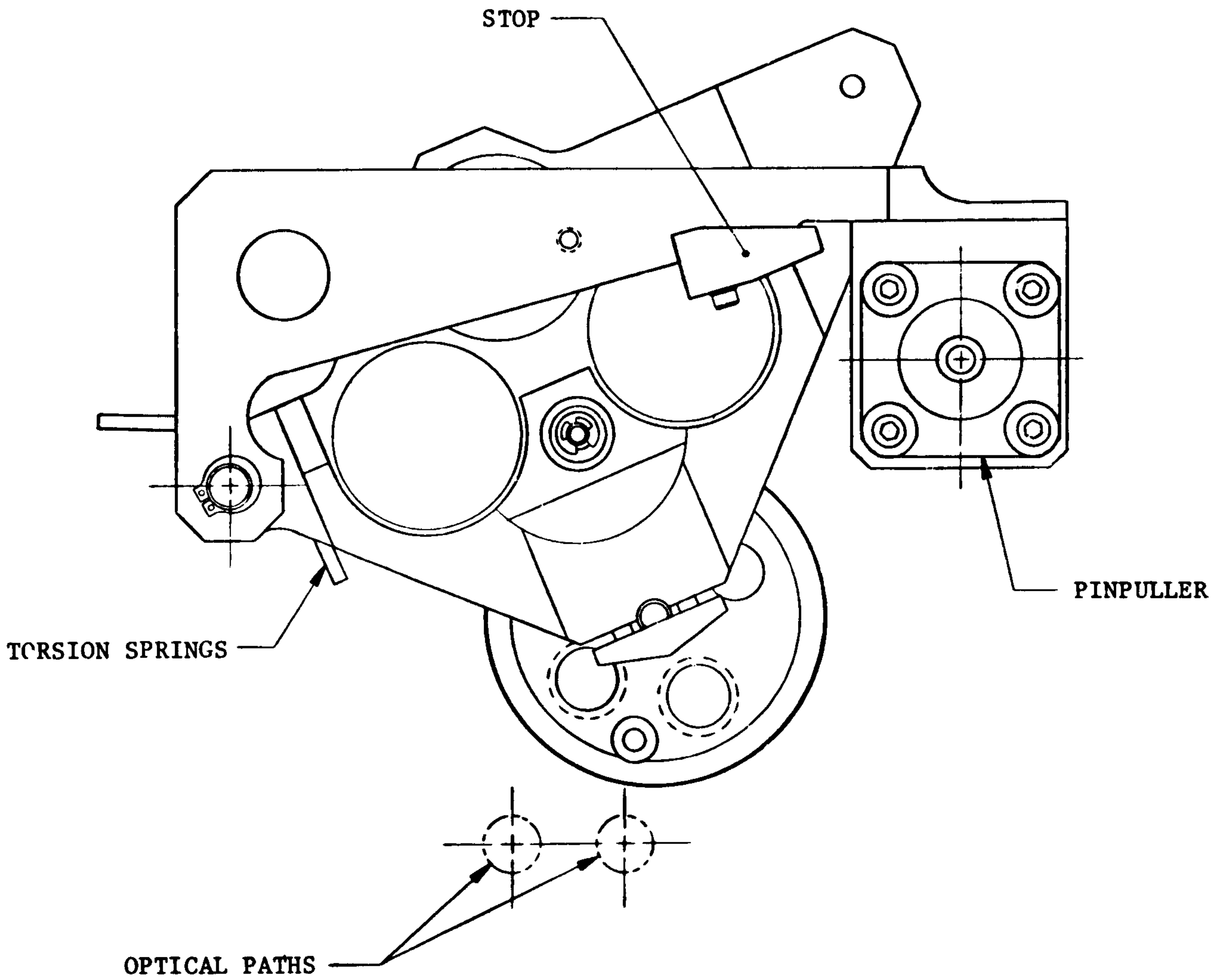

Figure 5. - Fail-safe Mode

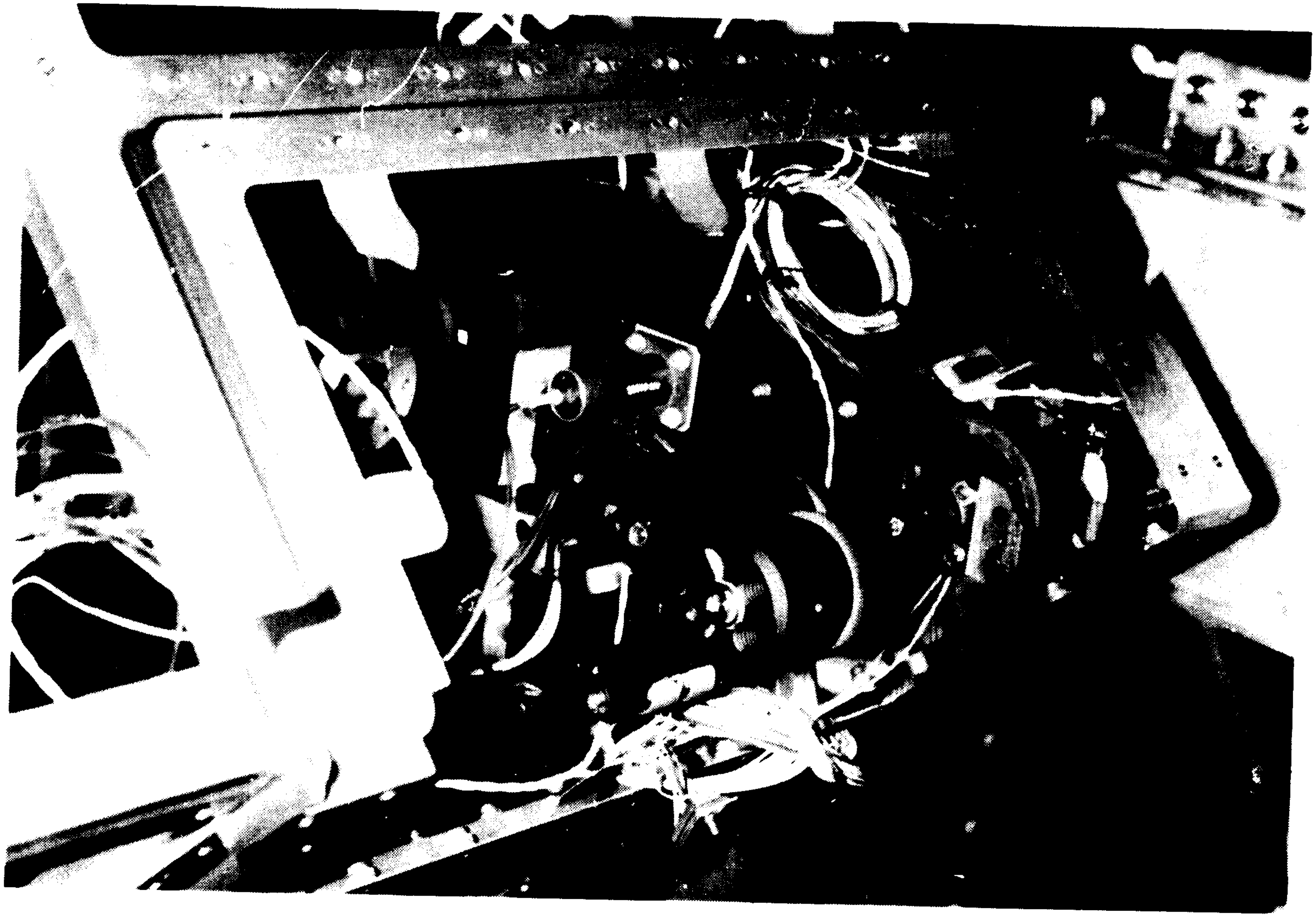

Figure 6. - Polarizer Installed in FOS

ORIGINAL PAGE IS
OF POOR QUALITY

Table 1. Repeatability Tolerances

		Wollaston Prism	Waveplate
θx, θy	Required	± 8	± 8
(arc min)	Predicted	± 1.1	± 3.2
	Measured	± 1.7	± 3.0
θz	Required	± 6	± 21
(arc min)	Predicted	± 3.0	± 12.6
	Measured	± 2.8	± 10.0